

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
14 July 2005 (14.07.2005)

PCT

(10) International Publication Number
WO 2005/063323 A1

(51) International Patent Classification⁷: **A61M 16/00**

(21) International Application Number:
PCT/AU2004/001833

(22) International Filing Date:
24 December 2004 (24.12.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/533,411 29 December 2003 (29.12.2003) US
60/545,658 18 February 2004 (18.02.2004) US

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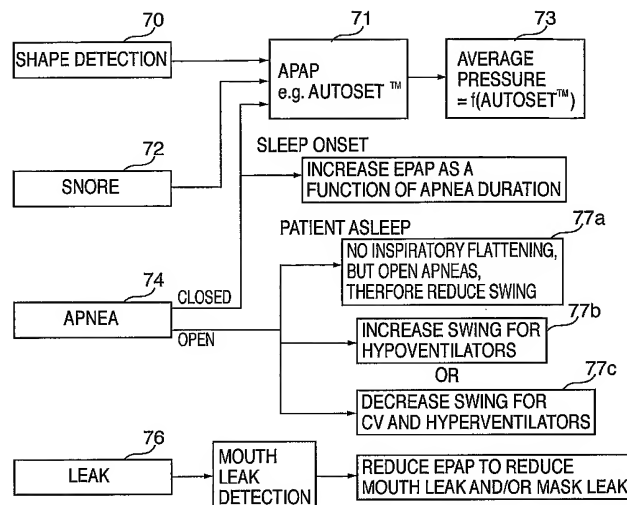
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: MECHANICAL VENTILATION IN THE PRESENCE OF SLEEP DISORDERED BREATHING



(57) Abstract: A method for controlling operation of a CPAP apparatus. The apparatus has a blower (2), a patient interface (6), an air delivery conduit (8) for delivering air from the blower (2) to the patient interface (6), a sensor (4p) for determining the pressure in the patient interface (6), and a control mechanism (15) that causes air to be delivered at a desired pressure to the patient interface (6) and that detects transitions between inhalation and exhalation of a respiratory cycle of a patient in order to synchronise the blower output with the patient's efforts. In one form the CPAP apparatus provides pressure in accordance with a bi-level waveform with at least one characterising parameter of the waveform being automatically adjusted in accordance with indications of sleep disordered breathing. The indications of sleep disordered breathing can be one or more of snoring, apnea, hypopnea, and flow limitation.

WO 2005/063323 A1



Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

MECHANICAL VENTILATION IN THE PRESENCE OF SLEEP DISORDERED BREATHING

This application claims the priority of U.S. provisional application No. 60/533,411
5 filed on December 29, 2003.

1. FIELD OF THE INVENTION

This invention relates to mechanical ventilation of sleep disordered breathing (SDB).

2. BACKGROUND OF THE INVENTION

A comprehensive background discussion of mechanical ventilation can be found in
10 "Principles and Practice of Mechanical Ventilation" (1994) Edited by Martin J Tobin,
published by McGraw-Hill Inc., ISBN 0-07-064943-7.

The use of nasal Continuous Positive Airway Pressure (CPAP) to treat Obstructive
Sleep Apnea (OSA) was invented by Colin Sullivan, see U.S. Patent No. 4,944,310.
Generally, the treatment involves providing a supply of air or breathable gas from a blower
15 to a patient via an air delivery conduit and a patient interface. While treatment is effective,
some patients find it uncomfortable. Improving patient comfort and compliance is a
continuing challenge.

One way to improve comfort is to provide a more comfortable patient interface. In
this regard, the ResMed MIRAGE™ masks have provided significant improvement in
20 comfort. See U.S. Patent Nos. 6,112,746; 6,357,441; 6,581,602 and 6,634,358. A more
recent development is the ResMed MIRAGE™ ACTIVA™ mask series. See International
Patent Application WO 2001/97893.

In the early days of nasal CPAP systems for treating OSA, patients were first titrated
in a clinical study to determine an optimal treatment pressure. Titration involves a patient
25 sleeping overnight in a clinic and being tested with a mask and CPAP device. The treatment
pressure provided by the CPAP device is adjusted until apneas are eliminated. The
treatment pressure is usually in the range of 4-20cmH₂O. A device would be set to that
pressure and given to the patient to take home. A subsequent development was the
automatically adjusting device that a patient could take home. The automatically adjusting
30 device will raise and/or lower the treatment pressure based on indications of obstructive
sleep apnea, such as snoring. Such devices are sometime generically referred to as
Automatic Positive Airway Pressure (APAP) devices. See U.S. Patent Nos. 5,245,995;
6,398,739; and 6,635,021.

Another type of nasal CPAP device provides a first pressure during inhalation (sometimes termed an IPAP) and a second, lower pressure during exhalation (sometimes termed and EPAP). Examples of these include the ResMed VPAP™ series, and the Respirationics BiPAP series. Bilevel CPAP devices may be prescribed for patients who do not comply with single pressure CPAP devices. Some patients perceive that the lower pressure during exhalation is more comfortable, at least while they are awake. A difficulty with these devices is deciding how to set the IPAP and EPAP pressures. If the EPAP is too low it may be insufficient to prevent obstructions, hence some clinicians may set the EPAP pressure to the pressure titrated during the sleep study. In those patients, the IPAP pressure, and thus the average pressure will be higher than that required to eliminate apneas.

Another form of automatically adjusting CPAP device is the ResMed AUTOSET™ SPIRIT™ device. In this device, the CPAP pressure is automatically increased or decreased in accordance with indications of flow limitation, such as flow flattening, snore, apnea and hypopnea. See U.S. Patent Nos. 5,704,345; 6,029,665; 6,138,675; and 6,363,933. An advantage of an automatically adjusting system is that over time the treatment pressure required may vary for a particular patient and a correctly functioning automatic system can obviate the need the patient to return for a subsequent sleep study. These patents also describe a method and apparatus for distinguishing between so-called "central" and obstructive apneas. The contents of all of the aforesaid patents are incorporated by cross-reference.

Another device for treating certain types of Sleep Disordered Breathing such as Cheyne-Stokes Respiration (CSR) is the ResMed AutoCS™ device. Among other things, this device provides a supply of air or breathable gas with a smooth comfortable waveform, sophisticated tracking of the patient's respiratory phase, and servo-control of patient ventilation. See U.S. Patent Nos. 6,484,719; 6,532,957; and 6,575,163 (the "AutoVPAP" patents). See also U.S. Patent No. 6,532,959. The contents of these patents are all incorporated by cross-reference.

Some OSA patients find treatment with the above devices uncomfortable and they become non-compliant with the therapy. Other patients such as cardiovascular patients with Congestive Heart Failure, patients with REM Hypoventilation, and patients with Respiratory Insufficiency could also benefit from a more comfortable and/or effective form of therapy.

3. SUMMARY OF THE INVENTION

In accordance with a first aspect of our invention, there is provided a mechanical ventilator with a bi-level waveform and an automatically adjusting mean pressure.

5 In accordance with another aspect of our invention, there is provided a mechanical ventilator that automatically adjusts End Expiratory Pressure in accordance with airway patency.

The invention also includes in one form a bi-level CPAP device with an automatically adjusting IPAP.

10 Another aspect of our invention is to provide a bilevel CPAP device which adjusts the EPAP in accordance with indications of apnea and the IPAP in accordance with indications of flow limitation.

In accordance with another aspect of the invention there is provided a method and apparatus for determining when mouth leak is occurring.

15 In accordance with another aspect of the invention there is provided a mechanical ventilator that automatically adjusts End Expiratory Pressure in accordance with leak.

In one form of our invention, the proportion into the overall respiratory cycle of the patient is continuously determined, the proportion into the overall respiratory cycle being used to scale the time-length of a pressure-time template, with the pressure delivered to the patient following the shape of the template but having a swing adapted to patient
20 requirements.

Additional aspects of the invention are described in more detail herein.

4. BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a structure of the preferred ventilator apparatus for implementing the methods of the current invention;

25 FIGS. 2A-2D illustrate some exemplary waveforms delivered according to various embodiments of the invention;

FIG. 3 is a pressure waveform template that is a function of a phase variable;

FIG. 4 is an inspiratory table of the inspiratory portion (0 - 0.5) of the waveform of the graph of Fig. 3;

30 FIG. 5 is an expiratory table of the expiratory portion (0.5 - 1) of the waveform of the graph of FIG. 3;

FIG. 6 is a block diagram of an embodiment of a device according to the invention;

FIG. 7 is another block diagram illustrating an application of pressure to a ventilator of the invention;

FIGS. 8A and 8B are illustrative functions for controlling swing as a function of an
5 automatic SDB pressure determination process;

FIG. 9 is a graph illustrating control of median pressure by an automated SDB pressure detection process; and

FIG. 10 is a graph illustrating mouth leak detection.

5. DETAILED DESCRIPTION

5.1 HARDWARE

A device in accordance with an embodiment of the invention comprises a blower and blower-controller. The blower can deliver a supply of air at positive pressure 2-40 cmH₂O, but generally in the range of 4-25 cmH₂O to a patient interface via an air delivery conduit. The device also includes a flow sensor to measure the flow of air along the conduit, and pressure sensors to measure the pressure of air at the blower outlet. In one form, the device alternatively includes an additional pressure sensor to detect the pressure in the patient interface.

For example, a preferred embodiment of the invention is illustrated in FIG. 1. The ventilator device may include a servo-controlled blower 2, a flow sensor 4f, pressure sensor 4p, a mask 6, and an air delivery conduit 8 for connection between the blower 2 and the mask 6. Exhaust gas is vented via exhaust 13. Mask flow may be measured by a flow sensor, such as a pneumotachograph and differential pressure transducer to derive a flow signal $F(t)$. Alternatively, the pneumotachograph may be replaced by a bundle of small tubes aligned in parallel with the flow from the blower with the pressure difference measured by the differential pressure transducer across the bundle. Mask pressure is preferably measured at a pressure tap using a pressure transducer to derive a pressure signal $P_{\text{mask}}(t)$. The pressure sensor 4p and flow sensor 4f have been shown only symbolically in FIG. 1 since it is understood that those skilled in the art would understand how to measure flow and pressure. Flow $F(t)$ and pressure $P_{\text{mask}}(t)$ signals are sent to a controller or microprocessor 15 to derive a pressure request signal $P_{\text{Request}}(t)$. The controller or processor is configured and adapted to perform the methodology described in more detail herein. The controller or processor may include integrated chips, a memory and/or other instruction or data storage medium to implement the control methodology. For example, programmed instructions with the control methodology are either coded on integrated chips in the memory of the device or loaded as software. As those skilled in the art will recognize, analog devices may also be implemented in the control apparatus. The apparatus of FIG.1 includes other sensors, communication interfaces and displays, a servo, etc., functional blocks the details of which are not necessary for an understanding of the present invention.

5.2 SYNCHRONY: TRIGGERING, CYCLING & PHASE DETERMINATION

In a device which varies treatment pressure throughout the respiratory cycle of the patient, it is more comfortable for the patient if the device varies the pressure in synchrony

with patient efforts. As illustrated in FIG. 6, an overall device 64 constructed in accordance with the principles of our invention includes an automated therapeutic treatment pressure determination component module 60 which determines a treatment pressure component to treat SDB, and a waveform module 62 or process for setting or selecting a waveform
5 (square, rounded, smooth, etc.) for modulating pressure in conjunction with the patient's respiratory cycle. Typically, the device will include a synchrony or triggering module 68 (controlled by fuzzy logic, pressure, patient effort, etc.) for determining states or the phase within the patient's respiratory cycle. Optionally, a central apnea detector 66 may be included.

10 In delivering pressure, the triggering module monitors the patient to make a determination of the patient's respiratory phase in order to synchronise the blower output with the patient's efforts. In one form, the determination is whether the patient is inhaling or exhaling (a discrete variable). In another form, the determination is of the proportion into the overall respiratory cycle of the patient (a periodic variable). Determination of phase may be
15 made by some combination of pressure, flow and effort sensors. For example, in one form, when mask pressure drops below a threshold, the transition to inhalation is taken to have occurred and correspondingly when mask pressure rises above a threshold, the transition to exhalation is taken to have occurred. In another form, when patient respiratory flow exceeds a threshold, inhalation is taken to have started and when patient respiratory flow
20 falls below a threshold, exhalation is taken to have started. In another form, patient respiratory phase is determined from analysing the shape of the respiratory flow curve and making a number of determinations as to the extent to which it is early inspiration, middle inspiration, late inspiration, early exhalation, mid-exhalation and late exhalation. See U.S. Patent Nos. 6,484,719; 6,532,957; and 6,575,163. Once a determination of phase has been
25 made, the shape of waveform to be delivered can be decided.

In one embodiment, a phase determination may be based on elapsed time of the particular portion of the cycle (inspiration or expiration) relative to a predicted total time for that particular portion of the cycle. For example, the phase within the respiratory cycle is determined as a ratio of the elapsed time to the expected total time. Since the total time for
30 the current cycle is not yet known, it is predicted by using an average time taken from a number of previous breaths, preferably taken from the previous five breaths of the patient. In the preferred embodiment, irregular breaths are excluded from the average. Thus, breaths of less than 150 milliseconds indicative of a cough or hiccup are excluded. Those skilled in the art will understand how to determine such a five breath average from a flow
35 signal.

With the determination of a continuous phase and utilizing the waveform module 62, smooth pressure changes are then implemented utilizing a pressure waveform template for inspiration and expiration that may preferably be stored in tables or arrays. In general, the tables store scaling factors for a predetermined breath length that when multiplied by a pressure amplitude in sequence will result in a pressure waveform that is represented by the scaling factors. Versions of these tables are illustrated in FIGS. 4 and 5 based on the smooth waveform of FIG. 3. As those skilled in the art will recognize, the tables may be substituted by mathematical equations rather than relying on a look-up operation. Moreover, although a sinusoidal rise/exponential decay curve is shown, the template may represent any shape of waveform, such as a square wave illustrated by the dashed lines of FIG. 3. Use of the phase variable ensures that each scaling factor (SF) of the table is utilized at an appropriate time in the patient's respiratory cycle, thereby compressing or expanding the time-length of the template. In this regard, the determined phase variable (elapsed time over total expected time) is used to scale the time-length of the template.

For these ends, a look-up operation that returns a pressure modulating function (Ins_Waveform) utilizing such a phase and an inspiratory table or array may be accomplished with the following:

$$\text{Ins_Waveform} = \text{Inspiratory_Table}(\text{I-Location})$$

where:

Inspiratory_Table is a function that returns a scaling factor from the table or array at a particular location determined by the I-Location function;

I-Location is a function that essentially identifies an inspiration phase variable within the current inspiration (i.e., the ratio of the elapsed inspiration time to the expected total inspiration time) of the patient as this relates to selecting an appropriate scaling factor from the table that will permit the delivered pressure to be modulated like that of a normal inspiration within the time scale of the patient's current predicted inspiration.

To accomplish this, the function returns an index of the inspiratory table as a function of (a) the current elapsed time of the inspiration (t_{switch}), (b) the time-length of the inspiratory portion of the waveform of the waveform template, which may be the number of table or array entries over which the inspiratory portion of the waveform template has been recorded in the table (total_entries); and (c) the predicted time for the inspiration portion of the respiratory cycle, i.e., the average inspiratory time (ave_insp_time). This index may be derived by the following formula:

$$\text{index} = \text{round} (t_{\text{switch}} * \text{total_entries} / \text{ave_insp_time})$$

Similarly, the look-up operation (Exp_Waveform) on the expiratory table or array may be accomplished with the following functions:

$$\text{Exp_Waveform} = \text{Expiratory_Table} (\text{E-Location})$$

5 where:

Expiratory_Table is a function that returns a scaling factor from the expiration table or array at a particular location determined by the E-Location function;

10 Much like the I-location function described above, E-Location is a function that essentially identifies an expiration phase variable within the current expiration of the patient (i.e., the ratio of the elapsed expiration time to the expected total expiration time) for the purpose of selecting an appropriate scaling factor from the table that will permit the delivered pressure to be modulated like that of a normal expiration but within the time scale of the patient's current predicted expiration.

15 To accomplish this, the function identifies an index of the expiratory table as a function of (a) the current elapsed time of the expiration (t_{switch}), (b) the time-length of the expiratory portion of the waveform of the waveform template, which may be the number of table or array entries over which the expiratory portion of the waveform template has been recorded in the table (total_entries); and (c) the predicted time for the inspiration portion of the respiratory cycle, i.e., the average inspiratory time (ave_exp_time). The index may be
20 derived by the following formula:

$$\text{index} = \text{round} (t_{\text{switch}} * \text{total_entries} / \text{ave_exp_time})$$

Those skilled in the art will recognize that other formulas may be utilized for modulating the ventilation pressure, such as a more simple cycling and triggering between an IPAP and EPAP.

25

5.3 INDICATIONS OF SLEEP DISORDERED BREATHING (SDB)

There are a number indications which can be used to detect sleep disordered breathing including snore, apnea, hypopnea and the shape of the inspiratory flow-time curve.

5.3.1 Snore

5 Snoring can be detected by a number of techniques as known in the art. For example, US Patents 5,245,995 (Sullivan et al.) and 5,704,345 (Berthon-Jones). For example a flow signal can be band-pass filtered in the frequency range of 30-300Hz and the intensity of the resultant signal determined.

10 Having detected snoring, a snore index can be calculated as described in the above patents. The index can be based on the intensity, frequency and duration of snoring. A "snore prevention pressure" can be defined as the minimum CPAP pressure necessary to prevent snoring.

5.3.2 Apneas & hypopneas

15 Apneas can be detected using a number of techniques as known in the art. For example, US Patent 5,704,345 (Berthon-Jones) describes an apnea detector as follows: The average flow signal variance calculated over a moving time window is compared with a threshold by a level detector, to generate an "airflow-ceased" trigger. This starts a timer. If the trigger persists for more than 10 seconds, a comparator declares an apnea. The threshold may be a fixed value, typically 0.1 l/sec, or may be a chosen percentage (typically 10 or 20%) of the
20 average ventilation over the last several minutes (typically 5 minutes). For convenience, instead of comparing the threshold with the square root of the variance, one can square the threshold, and compare with the variance directly.

25 Conversely, if airflow resumes before 10 seconds lapses, the timer is reset and no apnea is declared.

In one form, upon detection of an apnea, the device increases pressure until the apnea stops, or a predefined threshold is reached. In this way the pressure does not exceed safe levels. The amount of the increase in pressure can vary upon the pressure at which an apnea has occurred and the duration of the apnea. See US Patent 6,367,474 (Berthon-
30 Jones et al.)

Hypopneas can be similarly detected, however with a higher threshold, such as 50% of the average ventilation.

5.3.3 Flow limitation

5 Flow limitation can be detected by a number of techniques as known in the art. For example see US Patent 5,704,345 (Berthon-Jones) which describes using various flattening indices such as based on the mid-portion of the inspiratory flow-time curve. Other flattening indices are known. See US 6,814,073 (Wickham). A flow limitation prevention pressure can be defined as the minimum CPAP pressure necessary to prevent flow limitation. This pressure
10 is not predetermined, but calculated continuously in conjunction with various flow flattening indices. Pressure is increased until the indices indicate that flattening has been eliminated. The pressure level at which the indices indicate that flattening is eliminated is taken to be the current "flow limitation prevention pressure". In one form of our invention, the current "flow limitation prevention pressure" is automatically decreased with time unless an
15 indication of flow limitation is detected.

5.4 WAVEFORM SHAPE

Accordingly, the blower can deliver a generally square-shaped waveform, similar to that provided by the ResMed VPAP™ Series or a more rounded waveform, similar to that
20 provided by the ResMed AUTOSET CS™ product (see U.S. Patent No. 6,532,959), for example, having a sinusoidal rise and exponential decay. Furthermore, the blower can adjust the shape of the waveform between square and more rounded to balance comfort and effectiveness (See U.S. Patent No. 6,553,992). In one form, for example, when delivering a generally square wave, the device provides a higher pressure during an
25 inspiratory portion of the patient's respiratory cycle (IPAP) and a lower pressure during an expiratory portion of the patient's respiratory cycle (EPAP). In another form, for example, when delivering a more rounded waveform, a SWING and pressure setting are determined. The SWING is the difference between the highest and lowest pressures delivered to the patient. The pressure setting could be the base pressure in one form, or the peak pressure
30 in another form.

5.5 SOME EMBODIMENTS OF OUR INVENTION

5.5.1 First Embodiment: Automatic IPAP

In accordance with a first embodiment of the invention, a device is adapted to provide a generally square waveform having settings for IPAP and EPAP in a manner similar to
5 ResMed's VPAP III device. The device has a clinician-settable pressure setting for the difference between IPAP and EPAP, ΔP (sometimes called Swing). The device monitors patient flow and determines a treatment pressure using the same algorithm as ResMed's AUTOSET SPIRIT device. See US Patent 5,704,345. Upon detection of the beginning of
10 inspiration, as described above, the device provides a supply of air at the treatment pressure (IPAP = treatment pressure) and maintains that pressure throughout the inspiratory portion of the patients breathing cycle. Upon detection of the beginning of exhalation, the device decreases the supplied pressure to the treatment pressure less ΔP .

In this way the advantages of the automatically adjusting CPAP algorithm are brought to a
15 bi-level CPAP device.

5.5.2 Second Embodiment: Automatic EPAP or EEP

A second embodiment of the invention is similar to the first embodiment, except that the End Expiratory Pressure (EEP) or the EPAP pressure is automatically adjusted, and the IPAP is
20 a fixed delta pressure above the EPAP.

5.5.3 Third Embodiment: Automatic mean pressure

A third embodiment of the invention is similar to the first embodiment, except that the mean or median pressures are automatically adjusted, and there is a fixed delta pressure between IPAP and EPAP.

25 5.5.4 Fourth embodiment: Automatic Swing Control

In accordance with another aspect of the invention, the therapeutic treatment pressure is used to control the pressure difference between IPAP and EPAP, or the "swing". For example, when the device determines that the treatment pressure is small, e.g., 5 cmH₂O, then the swing is set to a small value, e.g., 0 or 1 cmH₂O, and when the treatment
30 pressure is large, e.g., 15cmH₂O, the swing is set to a larger value, e.g., 3 or 4 cmH₂O. In this way a device in accordance with the invention can be controlled to ensure that pressure

never drops below a threshold, for example, 4 or 5 cmH₂O. Such a form of control is illustrated by the function of FIG. 8A in which the swing is set as a function of detected therapeutic treatment pressure (APAP Treatment Pressure). An alternative function is illustrated in FIG. 8B in which the swing is restricted from falling below a minimum such as 1
5 cmH₂O.

As illustrated in FIG. 7, if an event of central apnea is detected, swing may be increased or decreased based on several conditions. For example, it may be reduced if partial obstruction is not detected. Alternatively, if based on an historic analysis of flow data performed by the device or a classification preset by a clinician, the current patient is a
10 hypoventilator (has experienced hypoventilation), the swing may be increased, for example, by a step up in the swing by a predetermined amount. Alternatively, if based on an historic analysis of flow data performed by the device or a classification preset by a clinician the current patient is a hyperventilator or CV patient, the swing may be decreased, for example, by stepping down the swing by a predetermined amount.

5.5.5 Fifth embodiment: "Shark-fin" waveform

A fifth embodiment of the invention is similar to embodiments one to three, except that instead of providing a generally square pressure-time waveform, the waveform has a "shark-fin" shape as indicated in Fig. 2D, 3, 4 & 5.

5.5.6 Sixth Embodiment: Automatic IPAP and EPAP

In accordance with a sixth aspect of the invention, IPAP and EPAP are separately automatically adjusted. In this form of the invention, two pressure levels are calculated automatically. The first pressure is the minimum pressure necessary to prevent apneas and hypopneas. The second pressure is the minimum pressure necessary to prevent flow
25 flattening. The EEP or EPAP is set to the first pressure and the IPAP is set to the second pressure.

The first pressure is calculated using the apnea and snore detectors described above. The second pressure is calculated from flow flattening or roundness indices as described above.
30 The second pressure is controlled to be at least equal to the first pressure, preferably 1-2 cmH₂O greater than the first pressure. In addition there is a predetermined maximum difference between the first and second pressures.

In one form, absent an indication of apnea or hypopnea the EPAP pressure is decreased. Similarly in one form, absent an indication of flow flattening the IPAP pressure is decreased.

5.5.7 Other embodiments

- 5 The minimum pressure, P_0 , delivered to the patient may be automatically controlled in conjunction with the pressure calculated by the automatic algorithms $P_{\text{therapeutic}}$ and an amplitude, A , calculated from the desired delta pressure between IPAP and EPAP. With regard to the preferred pressure delivery formula $P(t)$ illustrated above, such implementations may be achieved by setting P_0 in alternative ways as follows:

$$P_0 = \begin{cases} P_{\text{therapeutic}} \\ P_{\text{therapeutic}} - A \\ P_{\text{therapeutic}} - \frac{A}{2} \\ P_{\text{therapeutic}} - kA \end{cases}$$

10

In the first, the therapeutic adjustments generated from the SDB detection routine discussed above are applied to the end expiratory or baseline pressure. In the second, therapeutic adjustments are applied to the peak or end inspiratory pressure. In the third, therapeutic pressure is applied to the mean. Those skilled in the art will recognize that each of the first
15 three may be derived by the fourth formula by setting adjustment variable K appropriately. In one form, a waveform template function, such as one illustrated in FIG. 3 (either the solid smooth waveform or the dashed square wave), may be modified for purposes of applying the therapeutic adjustments to either the baseline, peak or median by adjusting the y-axis of the template to vary from either 0 to 1, -1 to 0, or -0.5 to 0.5 respectively. In such an
20 embodiment, P_0 may be adjusted directly by the therapeutic pressure determination process.

Similarly, as illustrated in the flow chart of FIG. 7, an embodiment of a bi-level device having IPAP and EPAP, the apparatus may increase the EPAP pressure as a function of apnea duration determined in the apnea detector 74.

25

Several examples of resulting waveforms that may be generated by a device in accordance with various embodiments of the invention are illustrated in FIGS. 2A-2D. In FIG. 2A a square wave is generated based on a fixed swing. The average of the ventilation pressure modulation gradually rises and then falls over time as a result of the automated detection of a therapeutic pressure that may be applied to the baseline, peak or median as previously discussed.

In FIG. 2B, the therapeutic pressure is applied to the peak pressure or swing of a square wave while the baseline is held fixed resulting in a gradually increased and then decreased swing or peak. This may be accomplished by varying or controlling the peak and/or the swing as a function of the therapeutic pressure while maintaining the baseline pressure fixed.

In FIG. 2C, the automatically detected therapeutic pressure is applied to the baseline pressure or the swing of a square wave. This may be accomplished by varying or controlling the baseline and/or the swing as a function of the therapeutic pressure while maintaining the peak pressure fixed.

In FIG. 2D, the automatic control described above with regard to FIG. 2A is illustrated with a smoother waveform function. Those skilled in the art will recognize that the control described in FIGS. 2A to 2C can also be applied to the smooth waveform function illustrated in FIG. 2D with results similar to that of FIGS. 2A to 2C respectively.

5.6 OTHER ASPECTS

5.6.1 Mouth leak detection

In one form, the apparatus includes mouth leak detection apparatus, particularly useful for detection of mouth leak when a nasal mask is used. During such treatment when a patient's mouth is open, typically occurring during exhalation, air delivered to the nasal mask may escape through the mouth, through the nose, and out the mouth if the mouth is opened. This is illustrated in the graph of FIG. 10. Thus, the apparatus may include a module, such as a software module or process, that receives a signal indicative of total leak from the mask, as well as a signal indicating whether the patient is inhaling or exhaling. Additionally or alternatively, the software module receives a signal which includes markers indicating trigger and cycle time points. The mouth leak detection software module analyzes the total leak signal and determines whether or not there is a mouth leak, or that the mouth

has opened resulting when leak increases coincident with exhalation. Such openings or mouth leak determinations may be counted and with the advent of a certain number of such events, which may be recorded, an indicator or warning from the device may inform the user or patient that a full face mask should be used. Alternatively, as illustrated in FIG. 7, in the presence of leak, the EPAP pressure or end expiratory pressure may be reduced to reduce mouth leak or any other detected mask leak. In one form, the software module integrates the total leak flow during inhalation to calculate total inhalation leak volume. A similar calculation is made to determine total leak exhalation volume. If the leak exhalation volume is greater than the leak inhalation volume by a threshold value, then the software module determines that mouth leak is present or that the mouth is opening or open during exhalation. The following equations may be used:

$$LV_i = avg_{Xbreaths} \left(\int_{t=trigger}^{t=cycle} Leak \, dt \right)$$

$$LV_e = avg_{Xbreaths} \left(\int_{t=cycle}^{t=trigger} Leak \, dt \right)$$

if $LV_e > LV_i + LV_{threshold}$ then mouth leak

Once leak flow has been detected, the result may be flagged by generating a warning such as an audible or visible alarm, or recording the event in a data log.

5.6.2 Advantages of our invention

The advantages of our invention are many. Many patients find the delivery of high levels of positive pressure uncomfortable, and this may disturb sleep quality. The positive pressure delivered by prior art devices can lead to mask leaks, mouth leaks, upper airway symptoms, air swallowing and difficulty exhaling. A principle of treatment is to deliver the minimal possible effective pressure. An APAP device is designed to deliver the minimal possible effective pressure, which may vary within a night and from night to night. Bilevel devices have been used to reduce pressure during exhalation. Apparatus in accordance with an embodiment of the invention combines the features of APAP with bi-level ventilation to reduce mean pressure and increase comfort.

A disadvantage of bi-level ventilators, such as BiPAP, for providing comfortable therapy in OSA is the rate of pressure change at the transition from exhalation to inhalation and from inhalation to exhalation. A device in accordance with an embodiment of the invention utilises a more gradual change in pressure delivery during a breath, and copies flow rates observed during normal quiet breathing.

5.6.3 Work of Breathing (WOB)

In patients with poor lung compliance, work of breathing is a significant contributor to energy expenditure. OSA coexists with reduced lung compliance in some disease states, notably congestive heart failure (CHF) where SDB is present in 50-65% of patients. In CHF, CPAP has been demonstrated to improve heart function through a variety of mechanisms. CPAP is poorly tolerated in this group. A device in accordance with an embodiment of the invention offers advantages of CPAP plus the ability to decrease WOB. The bi-level waveforms used by a device in accordance with an embodiment of the invention reduce muscle work required for ventilation. A device in accordance with an embodiment of the invention may be useful in reducing metabolic rate and hence demands on the left ventricle.

Central apneas are a feature of worsening congestive heart failure and may require a different Positive Airway Pressure (PAP) therapy, for example, that provided by the AUTOSET CS™ device discussed above. A device in accordance with an embodiment of the invention can monitor the frequency of central apneas and provide a warning to the patient or clinician that a different form of treatment is indicated.

Regular CPAP may be difficult to use in CHF due to increased intrathoracic pressure impeding venous return and reducing systolic blood pressure. The bi-level waveforms and peak mean pressures only when necessary used by a device in accordance with an embodiment of the invention will lead to a reduction in this side effect of PAP in CHF.

Non-Invasive ventilators are generally set a pressure that normalise ventilation throughout the night. In Rapid Eye Movement (REM) sleep, physiologic changes in respiratory drive, respiratory muscle tone and upper airway tone predispose to added reductions in ventilation compared to other sleep states. Ventilation required during other sleep states may be considerably less. In a device in accordance with an embodiment of the invention, the EPAP pressures are lower during non-REM sleep.

In some patients, particularly those with obesity hypoventilation and other causes of hypercapnic respiratory failure, the increased Upper Airway (UA) resistance encountered in REM is an important factor in observed reduction in ventilation. In a device in accordance with an embodiment of the invention, EEP is raised in response to airflow flattening in order to counter the effect which a changing UA resistance may have on ventilation. Thus, in a device in accordance with an embodiment of the invention, by using the minimum necessary EEP required to keep upper airway patency, mean pressures are reduced leading to increased comfort.

Compliance is an issue with low rates of acceptance of therapy with some conditions such as amyotrophic lateral sclerosis and obstructive airways disease. An important factor

is expiratory pressure. A device in accordance with an embodiment of the invention provides for a gradual elevation in expiratory pressures, and lowest possible mean pressures during therapy.

Many prior art ventilators use non-physiologic waveforms. While a fast rise-time is
5 important for some patients, for other patients it is more important to have a comfortable waveform. Hence a device in accordance with an embodiment of the invention provides a range of waveforms including more rounded, physiologic shaped waveforms with, for example, a slow falling pressure. The slow falling pressure can be particularly useful for Chronic Obstructive Pulmonary Disorder (COPD).

10 Although the invention has been described with reference to various embodiments as described above, it is to be understood that these embodiments are merely illustrative of the application of the various principles of the invention. Numerous modifications, in addition to the illustrative embodiments of the invention discussed herein, may be made and other arrangements may be devised without departing from the spirit and scope of the
15 invention.

For example other automatic CPAP algorithms may be used to determine the treatment pressure, such as P_{crit} (for example, as described in U.S. Patent No. 5,645,053 (Remmers et al.).

WE CLAIM:

1. In a CPAP apparatus having (i) a blower, (ii) a patient interface for a patient, (iii) an air delivery conduit for delivering air from the blower to the patient interface, (iv) a sensor adapted to determine the pressure in the patient interface, (v) a sensor adapted to determine the flow of air to the patient, (vi) a synchrony module programmed to determine transitions between inspiration and expiration of a patient's breathing cycle from at least one sensor and (vii) a control mechanism programmed to provide a supply of air at positive pressure in accordance with a predetermined pressure-time template, a method of controlling the blower operation comprising the steps of:
- 10 automatically determining at least one index indicative of the presence of sleep disordered breathing from the pressure or flow sensors,
- automatically determining a treatment pressure in accordance with the index of sleep disordered breathing,
- 15 setting at least one characterising parameter of the pressure-time template to the treatment pressure,
- controlling the blower to deliver a supply of air at positive pressure to the patient in accordance with the template and in synchrony with the patient's breathing cycles as determined by the synchrony module.
- 20 2. A method as claimed in claim 1 wherein the index indicative of the presence of sleep disordered breathing is a function of one or more of flow flattening, snoring, apnea and hypopnea exhibited in the patient's inspiratory flow-time curve.
3. A method in accordance with claim 1 in which said template is one of a square wave and a shark-fin wave.
- 25 4. A method in accordance with claim 1 in which the characterising parameter is a minimum, maximum or mean.
- 30 5. A method in accordance with claim 1 in which the characterising parameter is an EPAP or an IPAP.

6. A method in accordance with claim 1 in which the characterising parameter is an end expiratory pressure (EEP).

5 7. A method in accordance with claim 1 in which the pressure-time template has minimum and maximum pressure values.

8. A method in accordance with claim 1 in which the pressure delivered to the patient has a minimum value.

10 9. A method in accordance with claim 8 in which the minimum pressure delivered to the patient is about 4 cmH₂O.

10. A method in accordance with claim 1 in which the pressure-time template has a fixed swing.

15

11. A method in accordance with claim 1 in which the pressure-time template has a small swing when the treatment pressure is low.

20 12. A method in accordance with claim 1 further comprising the step of determining a second index of sleep disordered breathing.

13. A method in accordance with claim 12 wherein the first index is indicative of apneas and the second index is indicative of flow flattening.

25 14. A method in accordance with claim 13 further comprising the step of determining a second treatment pressure in accordance with the second index of sleep disordered breathing.

30 15. A method in accordance with claim 14 further comprising the step of setting a second characterising parameter of the pressure-time template to the second treatment pressure.

16. A method in accordance with claim 15 further comprising the step of setting an EPAP pressure to the first treatment pressure and an IPAP pressure to the second treatment pressure.

5 17. A method in accordance with claim 1 wherein said pressure-time template is stored in look-up tables or arrays.

10 18. In apparatus comprising a blower adapted to provide a supply of air at positive pressure, a nasal patient interface, an air delivery tube connecting the blower to the patient interface, a flow sensor adapted to monitor the flow of air to a patient along the air delivery tube, and a microprocessor, a method of detecting the presence of mouth leak comprising the steps of:

determining leak flow during an inspiratory portion of the respiratory cycle of the patient from the flow sensor;

15 calculating a leak volume during inspiration from the leak flow during an inspiratory portion;

determining leak flow during an expiratory portion of the respiratory cycle of the patient;

20 calculating a leak volume during exhalation from the leak flow during the expiratory portion;

flagging that mouth leak has occurred when leak volume during exhalation exceeds leak volume during inhalation by a threshold.

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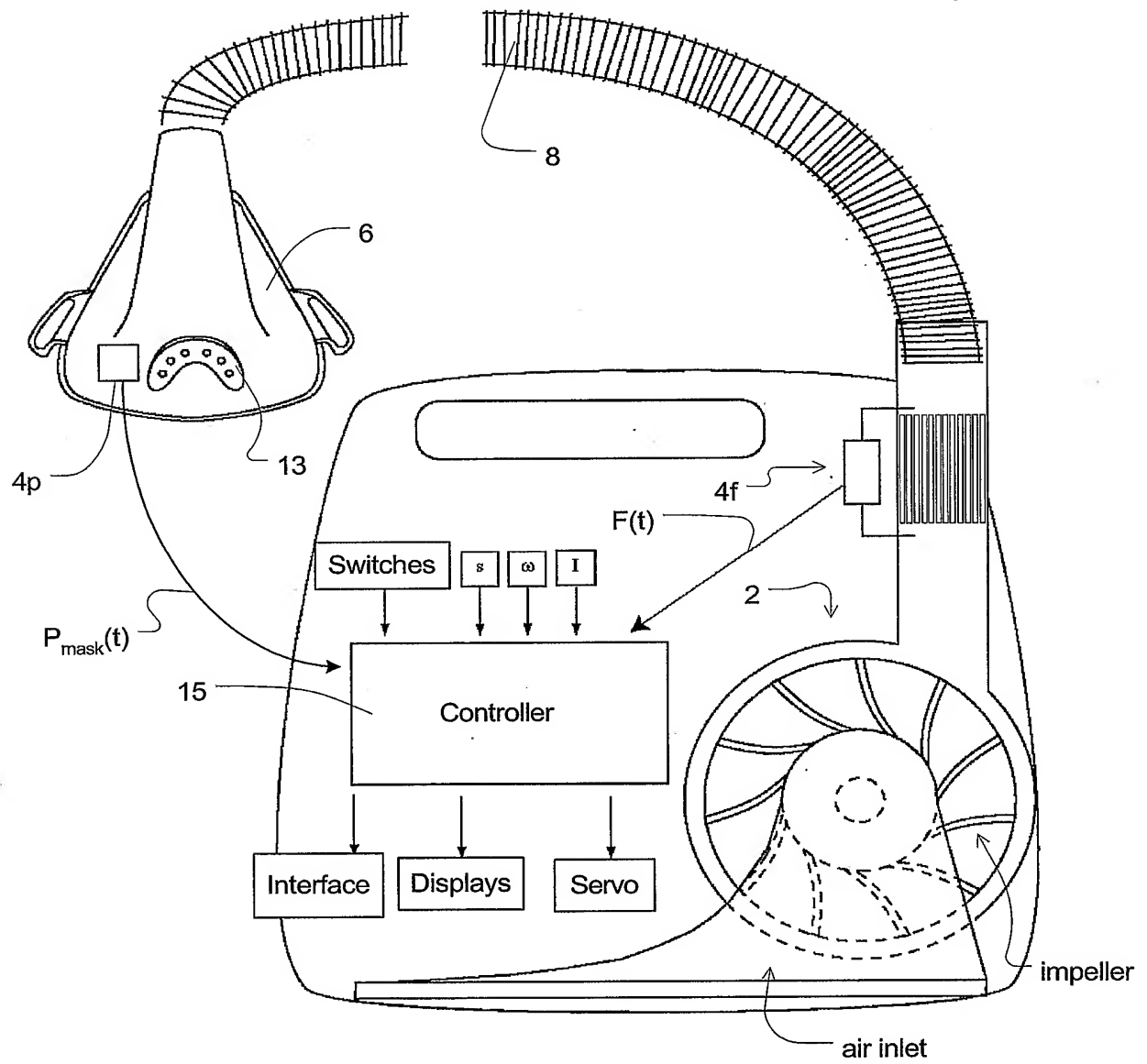


FIG. 1

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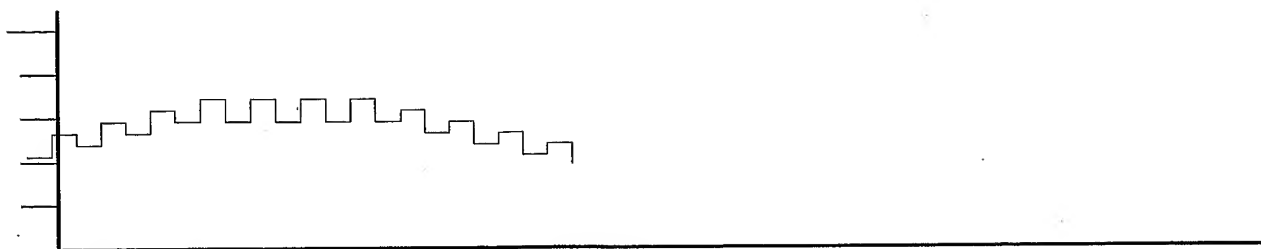


FIG. 2A

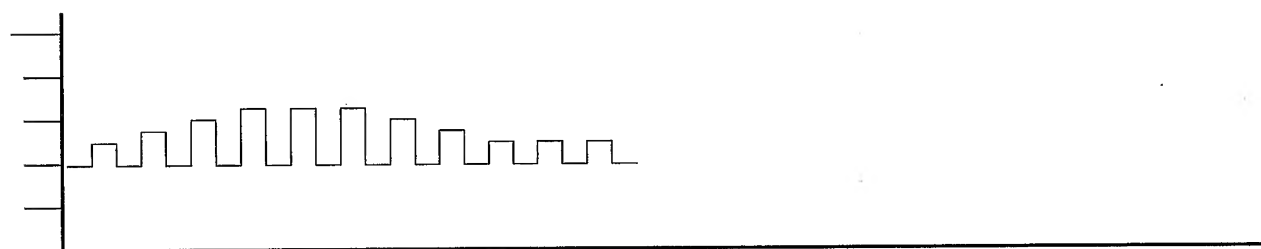


FIG. 2B

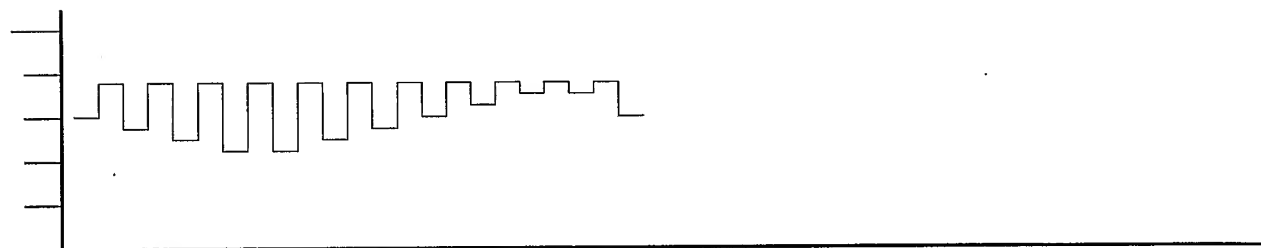


FIG. 2C

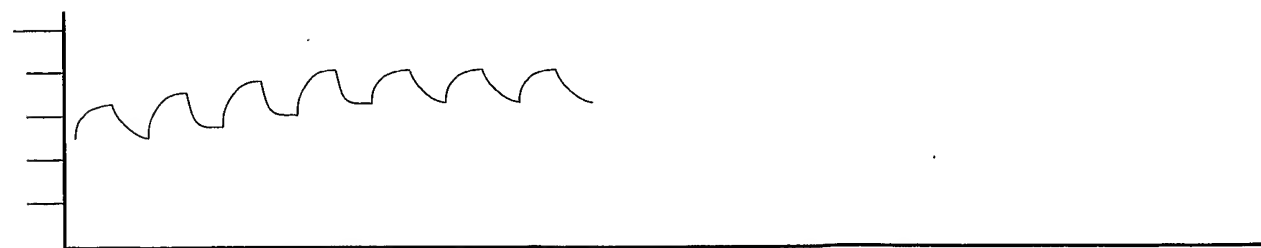


FIG. 2D

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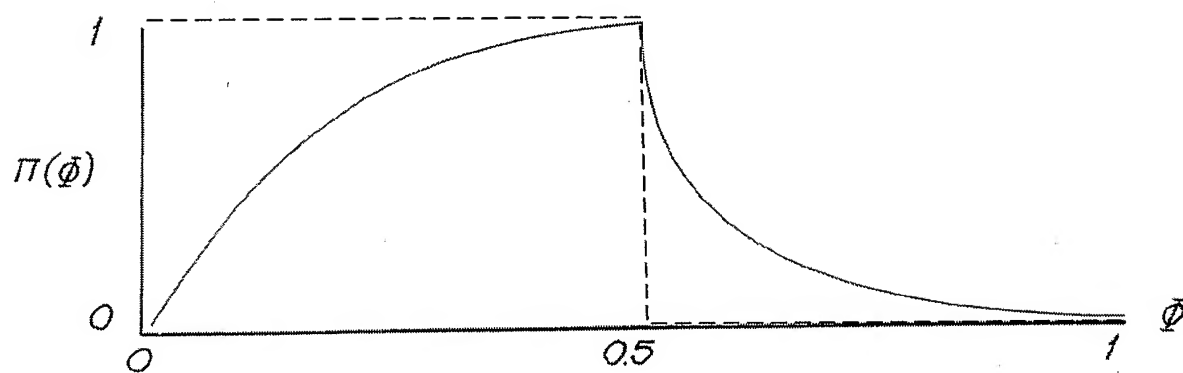


FIG. 3

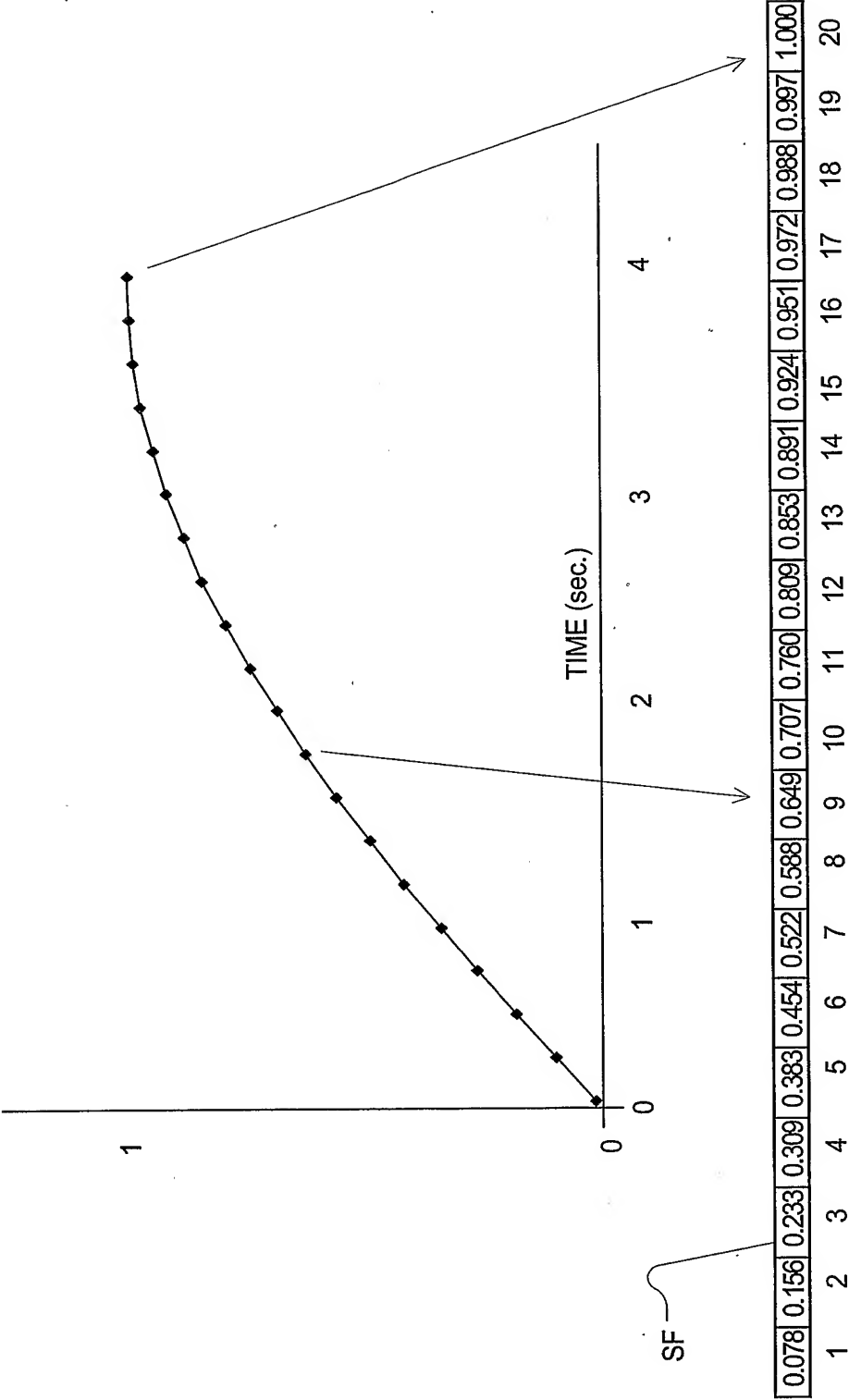


FIG. 4

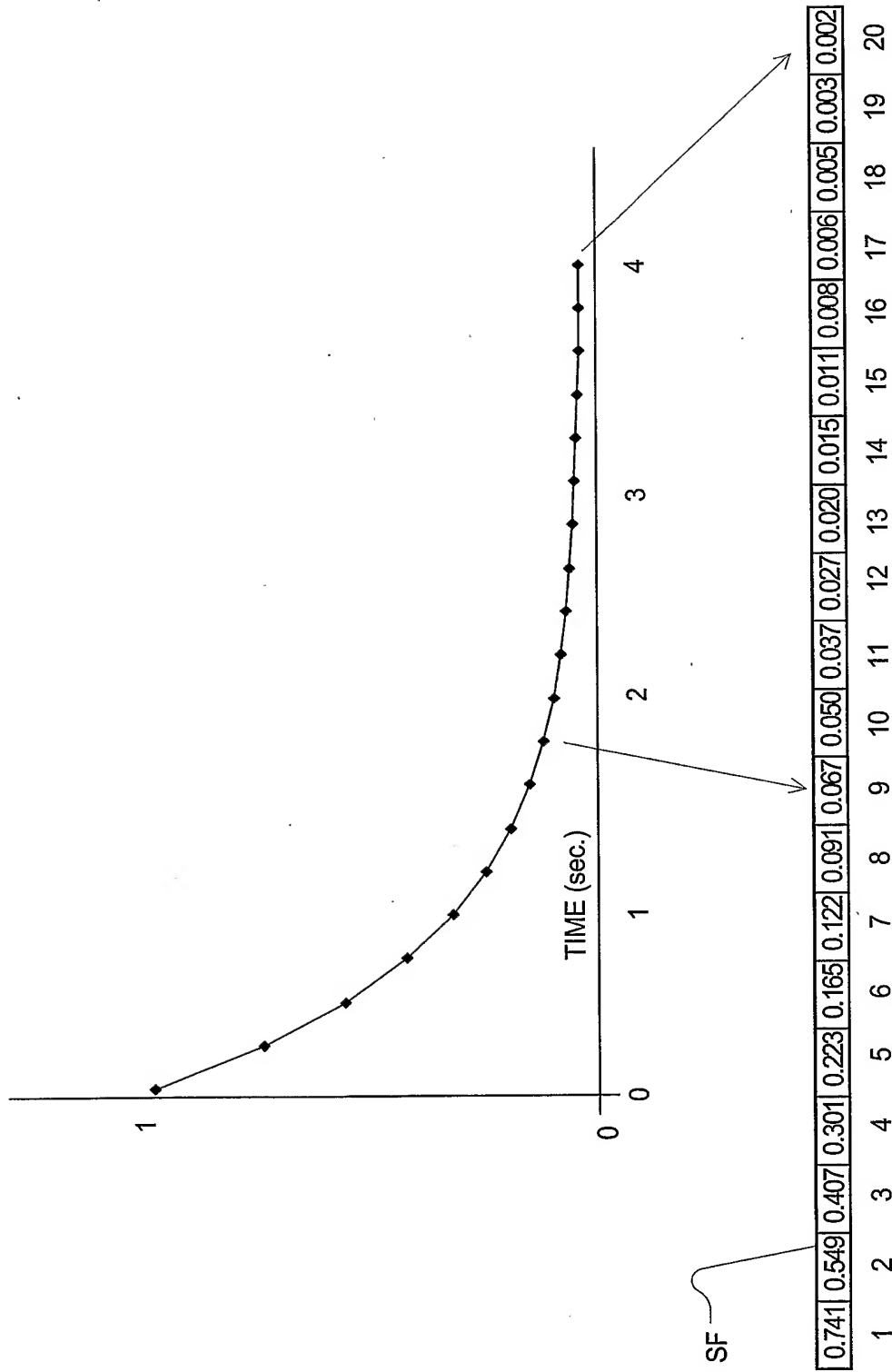


FIG. 5

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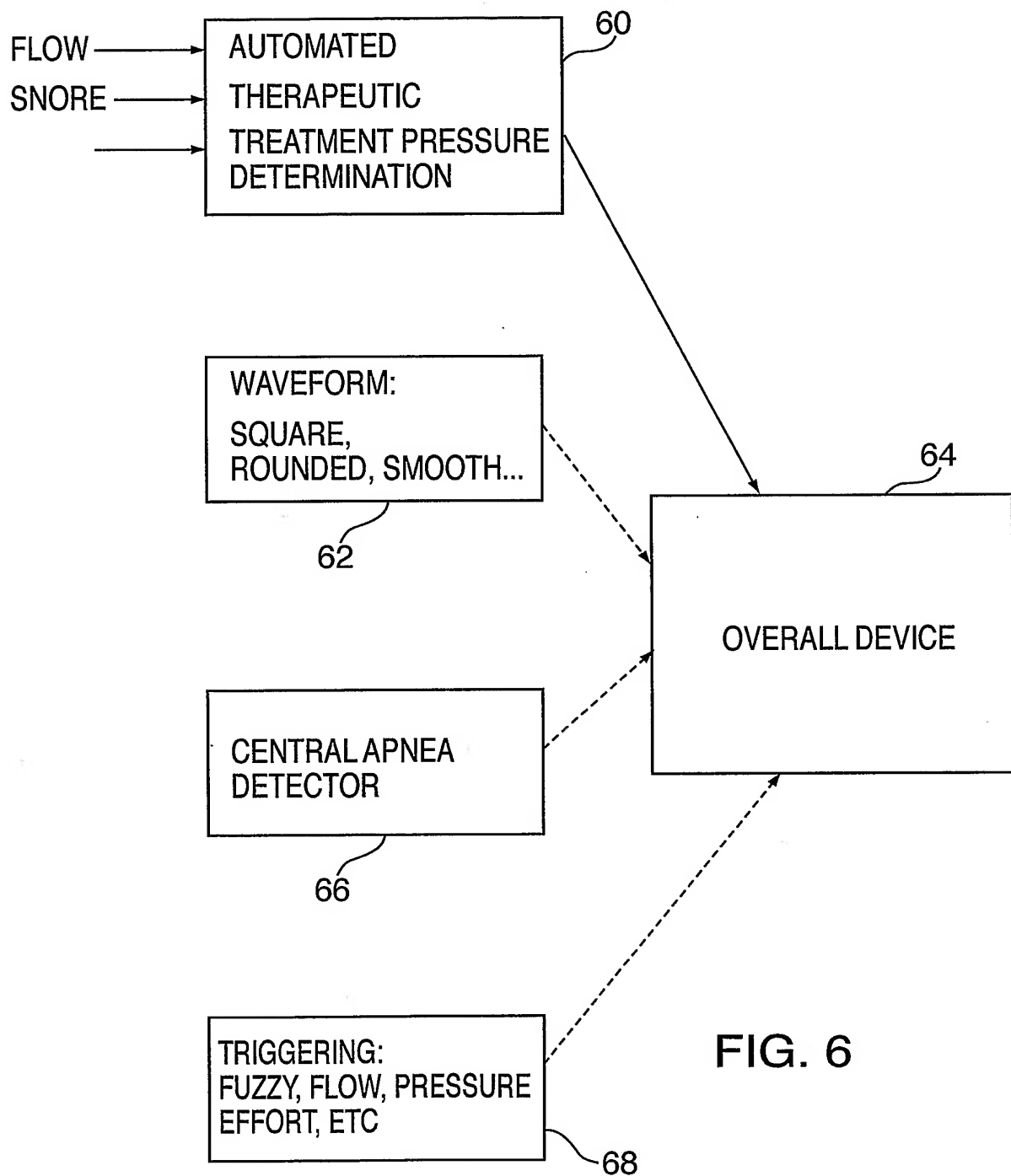


FIG. 6

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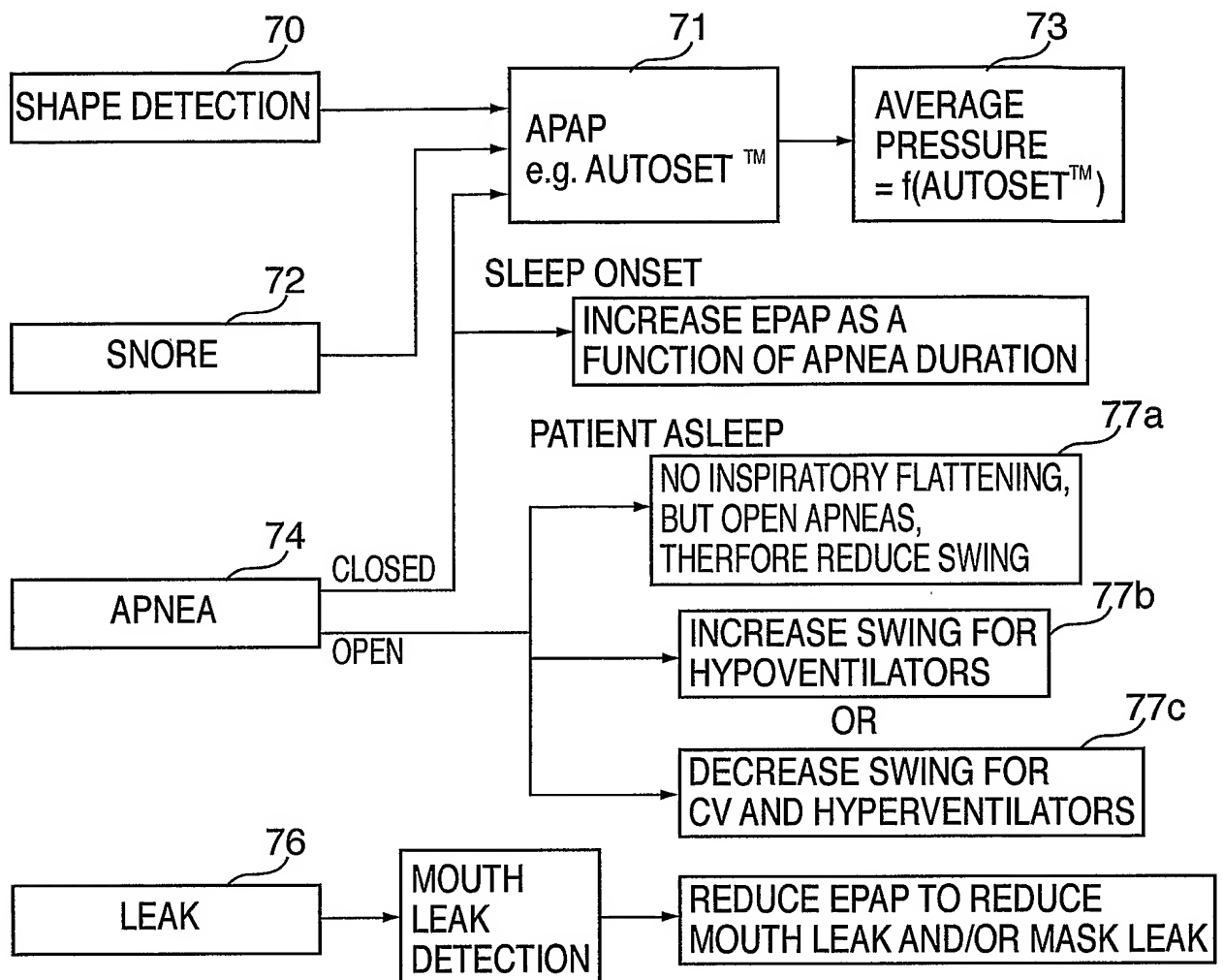


FIG. 7

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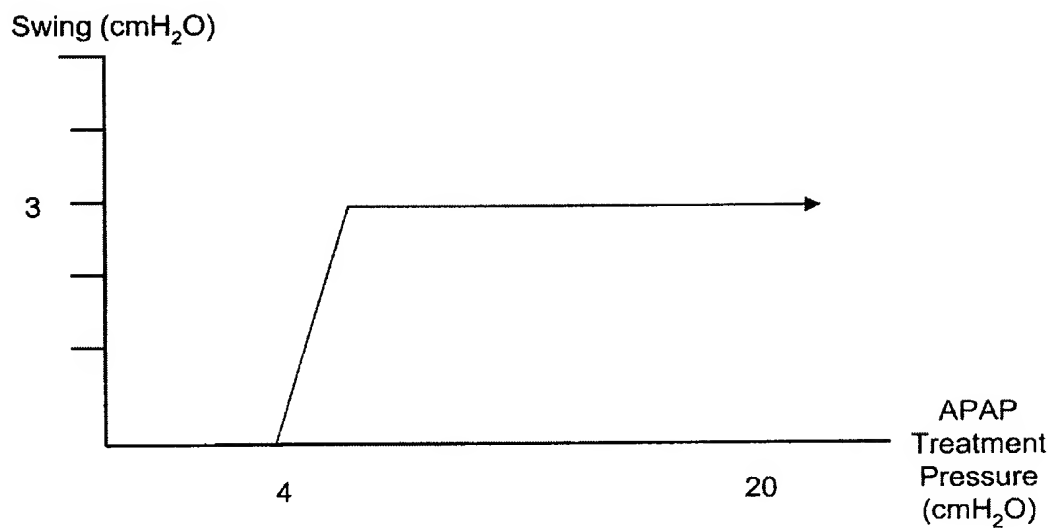


FIG. 8A

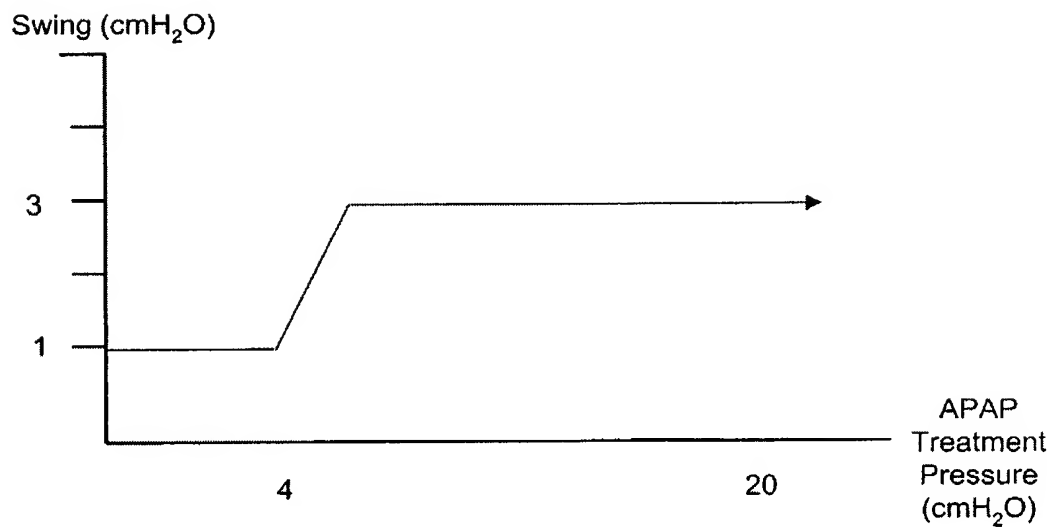


FIG. 8B

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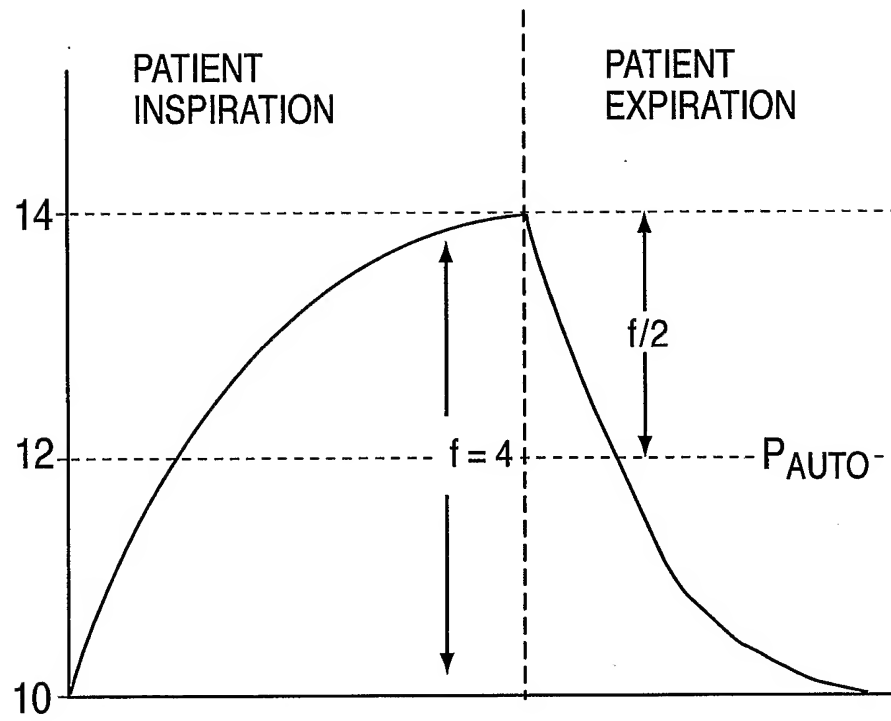


FIG. 9

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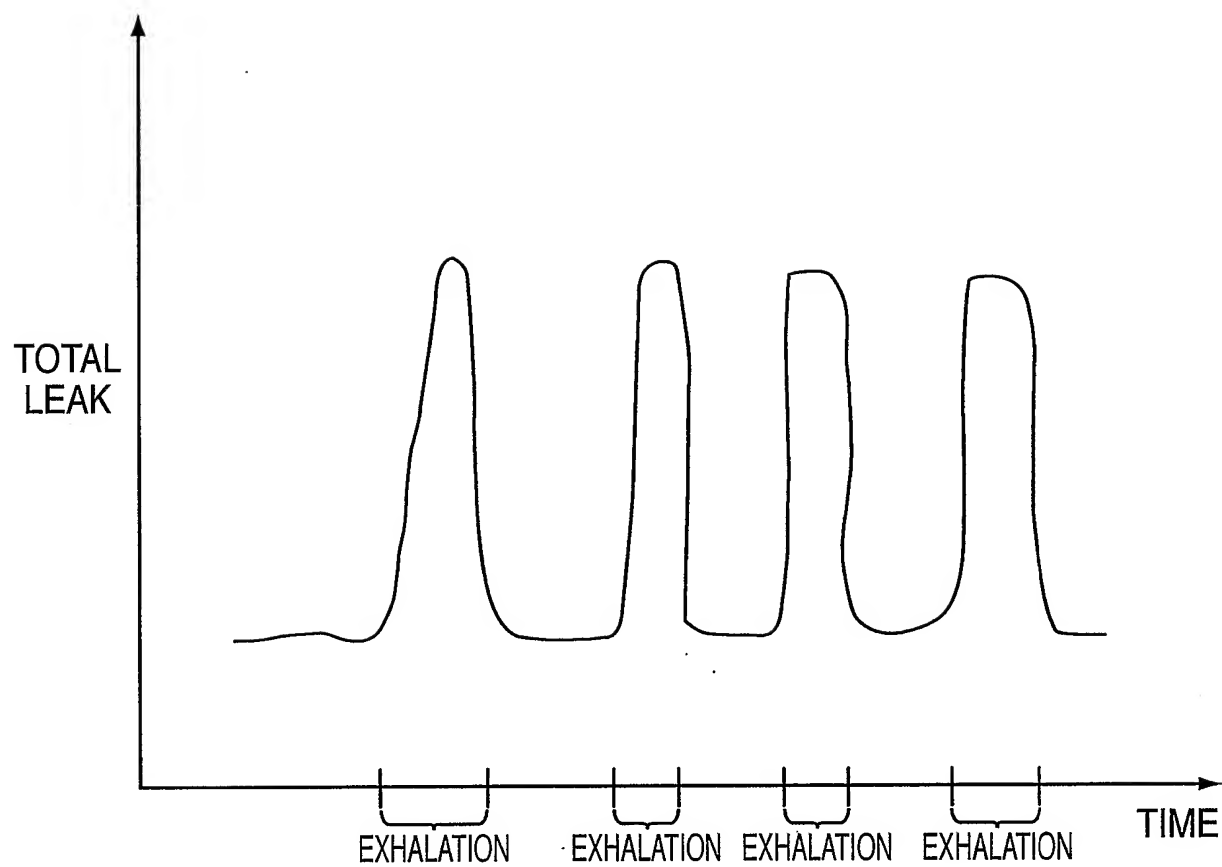


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2004/001833

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. ⁷: A61M 16/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI:IPC A61M & keywords: (breath, CPAP, ventilator, respirator, sense, detect, control, regulate, pressure, time, flow, index, synchronise, phase, predetermine, nasal, nose, nare, leak, difference, drop, mouth, volume) and similar terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2294400 A (INNOVATIVE MEDICAL SYSTEMS INC) 1 May 1996 Whole document	1-17
A	EP 0188071 B1 (TOTTORI UNIVERSITY) 3 August 1988 Whole document	1-17
A	DE 10164446 A1 (MAP MEDIZIN-TECHNOLOGIE GMBH) 10 July 2003 Whole document	1-17

☒ Further documents are listed in the continuation of Box C☒ See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
17 February 2005Date of mailing of the international search report
23 FEB 2005Name and mailing address of the ISA/AU
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2004/001833

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0956877 B1 (SIEMENS-ELEMA AB) 26 November 2003 Whole document	1-17
A	WO 2000/047260 A1 (MALLINCKRODT DEVELOPPEMENT FRANCE) 17 August 2000 Whole document	1-17
A	JP 2001259036 A (TEIJIN LTD) 25 September 2001 Whole document	1-17
A	AU 40463/95 (703829) B2 (SUNRISE MEDICAL HHG INC) 4 April 1999 Whole document	1-18
A	WO 2003/039637 A1 (FISHER & PAYKEL HEALTHCARE LIMITED) 15 May 2003 Whole document	18
P,A	WO 2004/078246 A1 (RESMED LIMITED) 16 September 2004 Whole document	18
P,A	JP 2004105230 A (TEIJIN LTD) 8 April 2004 Whole document	18

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2004/001833

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See attached sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

Supplemental Box

(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box No: III

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion the International Searching Authority has found that there are different inventions as follows:

1. Claims 1-17 are directed to CPAP apparatus and a method of controlling the blower operation. It is considered that the step of 'controlling the pressure in synchrony with the patient's breathing cycles' comprises a first "special technical feature".
2. Claim 18 is directed to a method of detecting the presence of mouth leak. It is considered that the 'method steps' comprises a second "special technical feature".

Since the above mentioned groups of claims do not share any of the technical features identified, a "technical relationship" between the inventions, as defined in PCT rule 13.2 does not exist. Accordingly the international application does not relate to one invention or to a single inventive concept, a priori.

It is considered that search and examination for the second invention will require more than a little additional search and examination effort over that for the first invention, and therefore an additional search fee is warranted.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU2004/001833

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
GB	2294400	CA	2161374	DE	19540344	FR	2726191
		US	5645054	WO	1993/024169		
EP	0188071	CA	1262223	JP	61131756	US	4681099
DE	10164446	NONE					
EP	0956877	JP	2000000307	US	6240920		
WO	2000/047260	CA	2361629	EP	1150731	FR	2789592
		US	6761167				
JP	2001259036	NONE					
AU	4046395	AU	13181/99	AU	40463/95	AU	93238/98
		BR	9505908	CA	2163855	EP	0722747
		US	5551419				
WO	2003/039637	NONE					
WO	2004/078246	US	2004231670				
JP	2004105230	NONE					
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.							
END OF ANNEX							